UCRL-JC-129870
PREPRINT

Development System Performance Issues of the NIF Master Oscillator and Pulse Forming Network

R. Wilcox
D. Browning
F. Penko
J. Rothenberg
G. Dreifuerst

This paper was prepared for submittal to the
Third Annual International Conference on
Solid State Lasers for Application (SSLA)
to Inertial Confinement Fusion (ICF)
Monterey, California
June 7-12, 1998

October 29, 1998

Lawrence Livermore National Laboratory

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Russell Wilcox, Donald Browning, Frank Penko, Joshua Rothenberg, Gary Dreifuerst

Lawrence Livermore National Laboratory, L-490,P. O. Box 808, Livermore, CA 94551

Abstract

A crucial step in the development of a complex laser system is initial testing of an integrated system. Issues arise at the system level which are not easily observed in component level testing. The NIF master oscillator room (MOR) contains a network of fiber and integrated optic components which can interact, potentially reducing system performance. Here we present some of the system problems we have seen in integrated tests and our solutions. Issues include ASE in the fiber amplifiers, filtering effects in the PM fiber, and regulation of average optical power.

1. ASE filtering

Our design for the MOR employs one master oscillator which is phase modulated, amplified, and distributed to 48 amplitude modulators to form shaped pulses. These pulses are fiber transported out of the MOR to the preamplifier modules (PAM's) in the laser bays. A block diagram of the system is shown in figure 1.

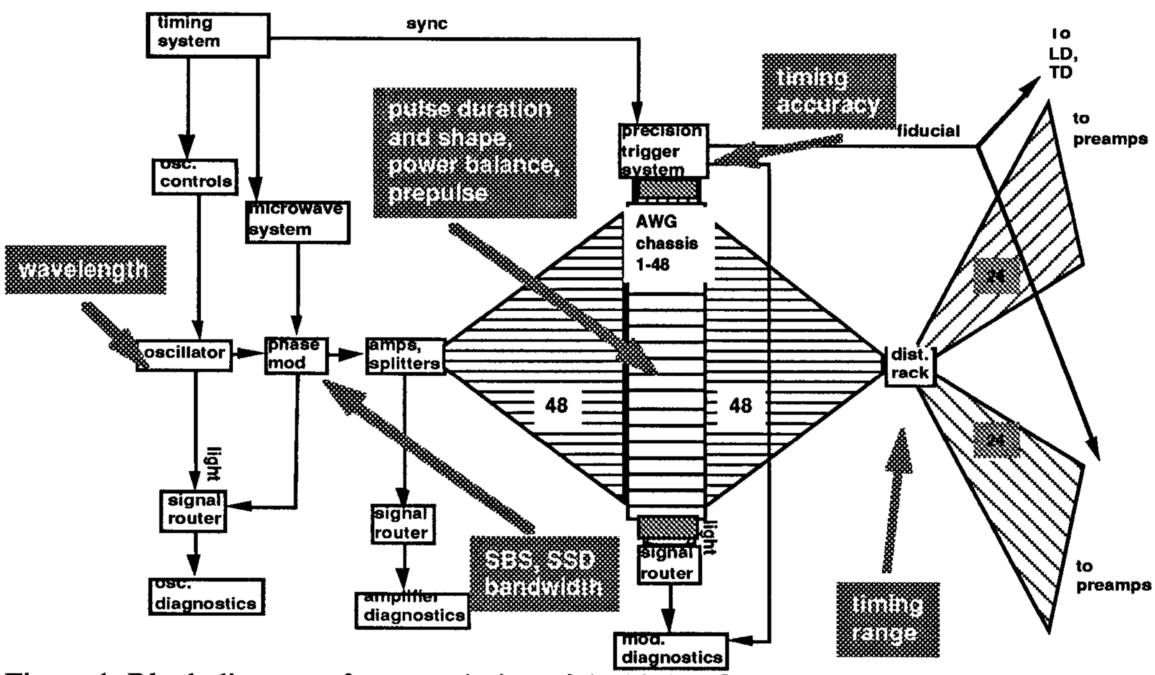


Figure 1. Block diagram of system design of the NIF MOR.

The amplitude modulators must shape the optical pulses with 275:1 contrast. The pulses delivered to the modulators by the fiber amplifier array are temporally flat, with pulse width of 30ns, determined by a modulator before the fiber amps. These fiber amplifiers will experience gain saturation, causing pulse distortion and drooping of the 30ns pulse, so the modulator before the amps pre-shapes the pulse to compensate. The fiber amps are also designed to produce about 2 microJoules output energy before the instantaneous gain drops by 1/e, to maximize output energy from the array and minimize pulse distortion.

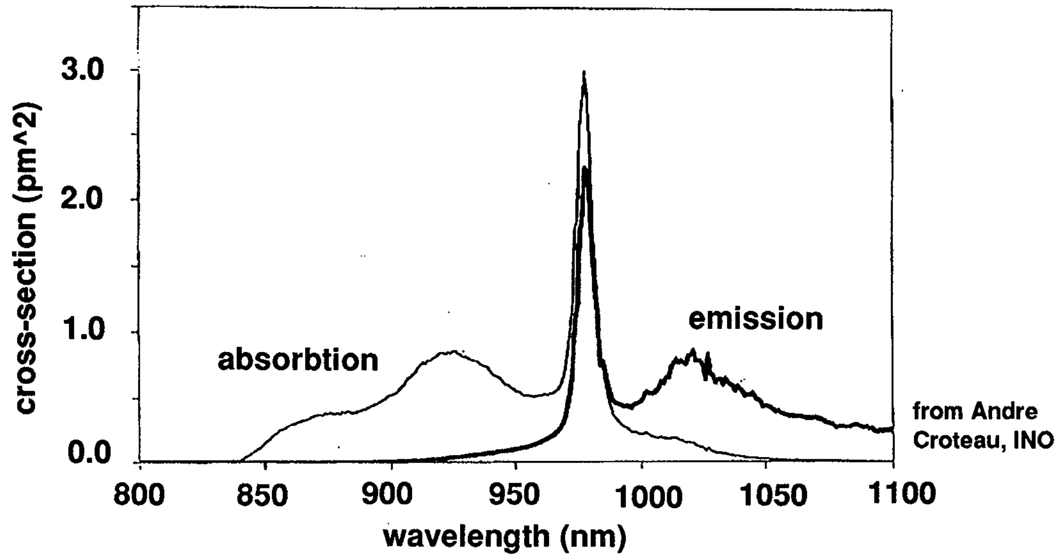


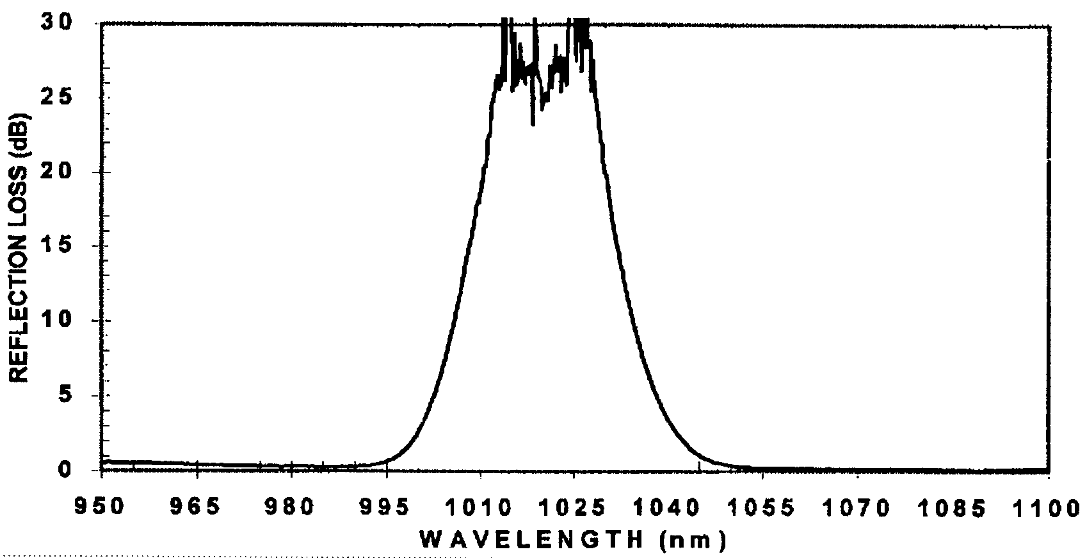
Figure 2. Absorption and emission spectra of Yb:silica.

Yb:silica is used as the gain medium in the fiber amplifiers, and its emission and absorption spectra are shown in figure 2. The ASE power emitted from the pumped fiber is mainly around 1020nm, so there is a band stop filter between the two stages of amplification to prevent ASE from the first stage from saturating the second stage. Still, some ASE near the signal wavelength is passed on to subsequent amplifiers, and can cause gain reduction due to saturation. This is what we observed when we built a system with three amplifiers in series. The amplifiers were separated by isolators, to prevent parasitic lasing.

	Single stage	In unfiltered chain	With interstage filter
Gain (small signal)	30	24	28

Table 1. Changes in fiber amplifier gain with and without interstage filters.

Table 1 shows the small signal gain per stage, and the gain of one stage in an unfiltered chain with an amplifier before it. This reduction in gain would make it impossible to achieve the needed power into the amplitude modulators. The solution was to introduce a 5nm FWHM bandpass filter between stages, which improves the single stage gain by 15% (including the introduction of filter loss of 15%), to an acceptable level. If the unfiltered ASE is allowed to propagate through the whole amplifier array, the gain reduction is more severe, resulting in a drop in small signal gain by a factor of 3, which is recovered with filters. Figure 3 shows the fiber amp interstage filter and the bandpass filter spectral profiles. Both filters are dielectric multilayers. Since we will be applying 0.5 nm of phase modulation before the amplifier array, we are currently ordering 5nm wide filters with flatter transmission profiles, to avoid modifying the FM spectrum.



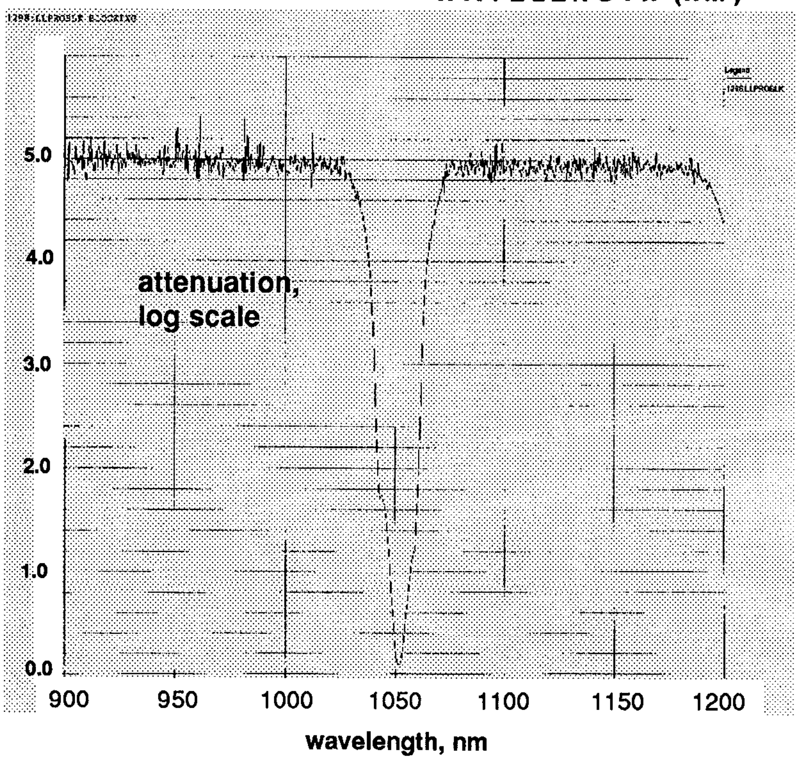


Figure 3. Transmission loss vs. wavelength for ASE filter in fiber amp (top) and interstage bandpass filter in isolators (bottom)

2. FM-to-AM conversion

There are in fact many components in the MOR which can change the amplitude or phase of phase modulation sidebands, causing unwanted amplitude modulation of the optical pulse. Some of these are described in detail elsewhere in this conference (1). We will be modulating at 3GHz modulation frequency to produce 1 Angstrom of bandwidth for suppression of SBS in the NIF frequency conversion crystals and other large optics, and at 17GHz modulation frequency to produce 5 Angstroms bandwidth for beam smoothing at the target (smoothing by spectral dispersion or SSD). If there is a change in either the phase or amplitude of the sidebands imposed by phase modulation, the pulse will exhibit amplitude modulation at the phase modulation frequency and its harmonics.

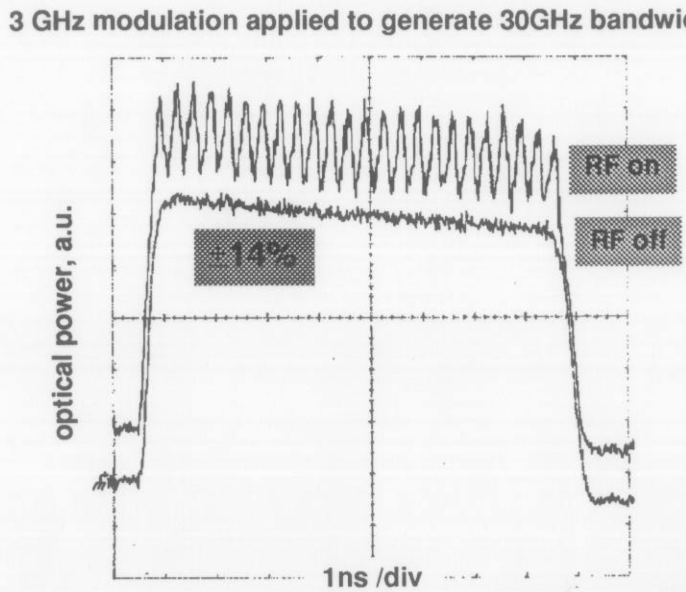


Figure 4. Amplitude modulation due to filtering of phase modulation.

Since the effects of unwanted spectral filtering are cumulative, and filtering occurs in several places in the system, one only sees the full effect when a test system is assembled. We observed this when we first applied phase modulation in our test system, as shown in figure 4. Most of this is due to filtering in the polarization-maintaining (PM) fiber and subsequent polarizers. A well-known type of birefringent filter is the Lyot filter (2), where a multi-order waveplate is followed by a polarizer. When light is launched into the waveplate at an angle with respect to the optical axes, the output polarization state is a function of wavelength, thus transmission through the polarizer is also a function of wavelength. In our case, the PM fiber is simply a birefringent fiber which exhibits polarization eigenstates along its optical axes, and is essentially a multi-order waveplate. For a beat length (2 pi phase lag between axes) of 2 millimeters, a 2 meter fiber is a thousand-order waveplate. Thus the filtering effect in these fibers is very pronounced, with a sinusoidal filter function with a period on the order of our FM bandwidth.

The requirements for pulse shape accuracy on NIF are stringent, due to requirements for symmetry of target illumination, and avoidance of high peak power in the laser which could cause damage. We have listed all significant sources of power error and estimated values of the RMS contribution of each in table 2, along with the frequency of the induced perturbation on the optical signal. The allowable error from the MOR is dependent on the frequency of the error, since for the target there is a 2ns integration specified, and this eliminates higher frequencies. Still, high frequency errors can contribute to damage in the laser, so they are accounted separately. Since there are so many sources of error, no one source can be allowed a large error budget. Thus the contributions from filtering of phase modulated signals (which we call FM-to-AM) must be made small.

Component	Frequency (Hz)	Est. RMS error (%)
Polarization drift	0.05	2
Timing cable drift	0.05	0.1
Oscillator energy	1000	1
AO chopper	1000	1
EO chopper energy	1000	0.5
Fiber amp gain	1000	3
AWG overall amplitude	1000	1
Timing trig energy	1000	0.5
Timing electrical noise	1000	0.5
Oscillator relax. osc.	1.00E+06	0.1
EO chopper shape	5.00E+07	0.5
AWG measurement err.	5.00E+07	1
AWG digital resolution	1.00E+09	0.00
AWG electrical noise	1.00E+09	1.5
SBS AM or FM-to-AM	3.00E+09	2
SSD AM or FM-to-AM	1.70E+10	2
Fiber amp ASE	5.40E+10	1

Table 2. Sources of power error in the MOR and estimated frequencies, magnitudes.

FM-to-AM due to Lyot filtering in the PM fiber can be reduced considerably by using polarizing fiber instead. We have shown (1) that use of fiber which attenuates light in one axis while passing the other can practically eliminate this effect. This type of fiber is produced commercially for telecom wavelengths, so we are having special fiber made for our wavelength which will be used throughout the MOR and distribution to the PAM. To emphasize the point of this paper, this is a system-wide design change initiated by experiments on an integrated system where systemic effects are readily observable.

3. Pulse power regulation

Another contributor to power error in the MOR is slow variation of power due to drifts in the oscillator, transmission through components, amplifier gain etc.. The time scale of these changes can be on the order of seconds to minutes, allowing for the use of slow control loops to regulate the average power.

We found in system tests that there are drifts in overall transmission of nearly 50% due to cumulative polarization errors and changing birefringence in the PM fiber. If there are several birefringent fibers in series, and each one has some random error in angular orientation of its axes with respect to the next, a sort of polarization “rocking effect” can be seen where the output polarization has accumulated a very large error. The actual birefringence of each fiber is a function of temperature, since the stress birefringence in PM fiber is induced by differences in thermal expansion coefficients of components of the fiber cladding. Thus the transmission through a series of PM fibers and subsequent polarizer will be a function of temperature and will change over a period of minutes depending on the environment. A change to polarizing fiber would eliminate this particular effect, but without such fiber we decided to implement a regulator. When we build the NIF MOR with polarizing fiber, additional slow variations of power in the MOR may remain, necessitating the use of a regulator in any case.

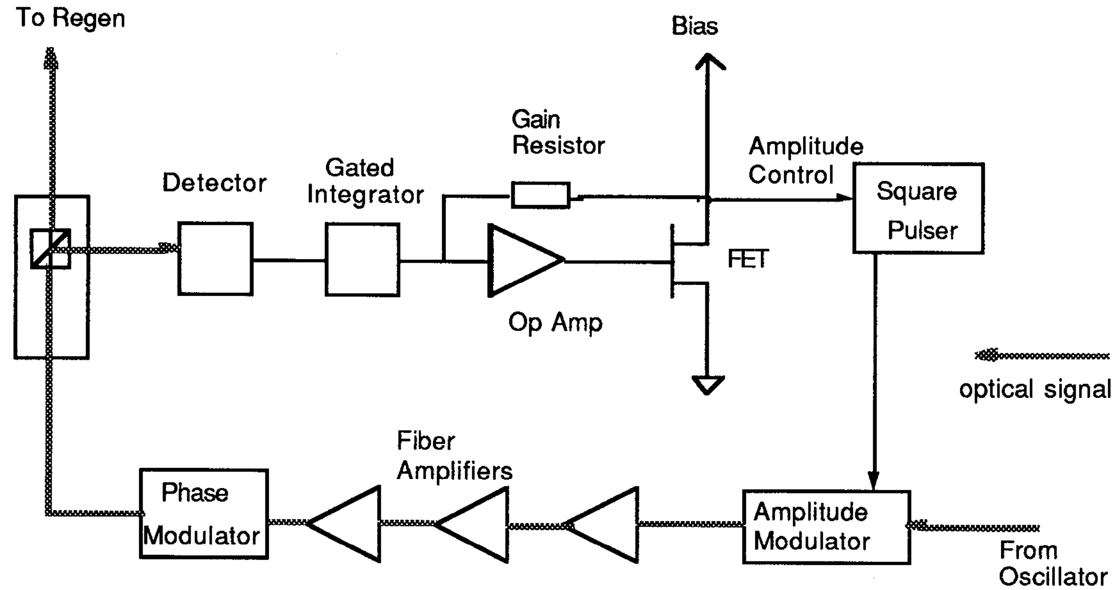


Figure 5. NIF MOR development test system with average power regulator.

A block diagram of the regulation setup in the MOR test system is shown in figure 5. We already were using a dual electrooptic modulator in the test system, but only one modulator was being driven, leaving the other for a regulator function. The test system originally reflected the component staging of the NIF MOR design, but was reconfigured for better performance with PM fiber, and to reduce the number of modulators in the optical path.

A sensor at the end of the chain, before launching into a long transport fiber which feeds the prototype PAM, senses the average power. Typical pulse parameters delivered to the PAM were about 1nJ in 8ns at 980 Hz repetition rate. To regulate the average power, the sensor signal is sampled and held by a gated integrator synchronized with the pulse, and the amplified output of this integrator controls the pulse voltage applied to the EO modulator. Figure 6 shows the average power vs. time with the regulator off and on, indicating an improvement in power stability by a factor of 4. The stability is still not what is required of NIF, due to shot-to-shot variations in oscillator energy. We are working on developing a higher stability oscillator with internal regulation loops to minimize short term variations. A feature of using waveguide electrooptic modulators is that this regulator was implemented all in low voltage electronics, without the need for a high voltage amplifier which would be required with a bulk EO modulator.

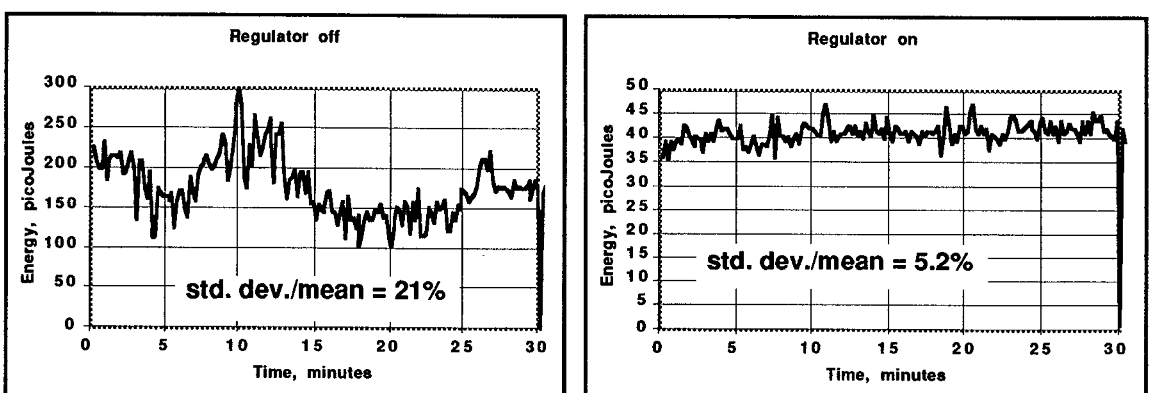


Figure 6. Pulse power without and with feedback regulator.

Conclusion

Initial measurements of MOR development system performance have revealed several issues that were less apparent during component development. We have identified the causes of these problems and found solutions which will be included in the final NIF design. Our experience illustrates the fact that for complex systems, a crucial development step is initial system integration.

References:
1. Joshua E. Rothenberg et al, “The issue of FM to AM conversion on the National Ignition Facility” in this conference.
2. Mark Johnson, “Single-mode-fiber birefringent filters”, Opt. Lett. **5**, p. 142 (1980).

This work was performed under the auspices of the U.S. DOE by LLNL under contract No. W-7405-Eng-48.